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ON FLOATS AND FLOAT TESTS

By Friedrich Seewald

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ON FLOATS AND FLOAT TESTS*

By Friedrich Seewald

The principal source of information on float resistance is the model test. In view of the insuperable difficulties opposing any attempt at theoretical treatment of the resistance problem, particularly at attitudes which tend toward satisfactory take-off, such as the transitory stage to planing, the towing test is and will remain the primary method for some time to come. Consequently, the importance of the model test from the viewpoint of reduction of model test data to full scale cannot be overestimated.

When a model test is not in close agreement with actual full scale experience as, in fact, one phase of the float tests postulates, one is apt to become skeptical as to the validity of the law of similitude, and for that reason the underlying principles of these questions are discussed first.

When, as is accepted practice in model float experiments, the forces impressed by a fluid flow on a body are measured, the total force set up by the fluid can, strictly speaking, be similated to another geometrically similar body in its entirety only when it is known that the individual components of this force which are contingent upon different physical properties change in the same ratio while being reduced to other body dimensions. Foremost among these components is the force produced by skin friction, that is, by the viscosity of the fluid. Next in importance is the force due to the mass inertia of the water particles owing to their deflection from their direction of motion. Third, is the force due to gravity in so far as the pressure varies with the depth of the water, and in the change in pressure distribution attributable to the variation in water level by the waves. (Other possible

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* "Über Schwimmer und Schwimmerversuche." From Zeitschrift fur Flugtechnik und Motorluftschiffahrt, May 15, 1931, pp. 265-276.

effects, such as compressibility, surface tension, etc., are to be disregarded, since the influence of these fluid characteristics on the resistance is probably of no more than secondary importance.)

Unfortunately, even the three kinds of forces (pressure or shear in friction) under discussion do not follow the same law when reduced to other scales or speeds. Those forces or pressures due to the mass inertia of the fluid follow the law of the square of the resistance, which postulates that the force vary proportionate to the product of fluid density to the area of the body and the square of the speed. This is a direct inference from Newton's law of mechanics. Consequently, this proportion of the total force must be reduced conformably to the law of the square of the resistance, regardless of whether it pertains to boats, floats, or airplane wings, because any other law of similitude would reduce this force component erroneously.

Now, when some other force component does not increase as the square of the speed and proportional to the area, but in some other arbitrary manner, perhaps even unknown to us, then it becomes readily apparent that reduction of the total force is at all feasible only when it becomes possible, in some way, to identify such attitudes, in which this proportion also is in the same relation as the component which follows the law of the square of the resistance. Since geometrical similitude in all parts is an unconditional premise for any reduction, the conditions of two comparable attitudes can only be altered by a corresponding selection in model scale and speed. A criterion for the choice of scale and speed which ensures that the force, due to gravity owing to differences in levels (generally called wave making resistance), has increased in the same ratio as that component which follows the square law of the resistance, is the so-called Froude law. This law stipulates that the reduction of the measured force must follow the law of the square of the resistance. But there is one provision which proscribes that this conversion in such processes, in which the gravity affects the resultant force, is applicable only when, aside from geometrical similarity of both bodies, the Froude number $v^2/g\,l$ is the same in both cases, wherein v = speed, l = arbitrary body length, and g = acceleration of gravity.

The physical sense of this number becomes readily ap-

parent when expressed as

$$\frac{\gamma/g\ v^2}{\gamma\ l}.$$

Then it is seen it denotes the ratio of the dynamic to the static pressure. When these two pressures on two geometrically similar bodies assume the same relation on two corresponding surface elements, the forces set up by these two different kinds of pressure are in the same ratio also. Once this is known the magnitude of the two components of the force is of no moment, and the total force can be converted into the thus characterized dimensions and speeds conformably to that law which in general is applicable to one of those two components. This is the sense of Froude's law as well as of all other laws of similitude. I have used the occasion to go more into details about these comparisons than the subsequent considerations may perhaps warrant. But in the light of discussions on Froude's law and the limits of its validity these principles, no matter how obvious they may seem, are not always kept in view.

In problems on objects afloat in ideal fluids this law would suffice for conversion. But, since the fluids appearing in nature, set up, because of viscosity, shearing stresses on the surface of the object, these forces, which again may follow any other arbitrary law, must be made to conform to the same conditions as the other remaining force components, namely, that the shearing stresses on the surface must assume the same relationship in the comparable attitudes as the pressures which are amenable to the law of the square of the resistance. But the fluid friction on the surface of the object is, according to the definition of the coefficient of friction, proportional to $\mu\ v/l$, with μ = friction coefficient. An attempt to retain the explained condition for the proportion of the friction also, would result in

$$\frac{\gamma/g\ v^2}{\frac{\mu\ v}{l}}$$

assuming the same value in the two comparative attitudes. However, this ratio is nothing more than the Reynolds Number expressed differently, as becomes evident when multiplying numerator and denominator by $g\ l/v\ \gamma$.

These two conditions of Reynolds and Froude can only be fulfilled for equal size and equal speed; a model test at more reduced scale is impossible. Any attempt in spite of this, to apply the law of the square of the resistance to the friction component to model testing signifies that the friction effect is either considered as small or that at least the deviations in frictional resistance from the square of the resistance are very minute. These two assumptions do not hold true in many practical cases.

As regards the total frictional force set up on the whole wetted surface, this assumption would indicate that the resistance coefficient had the same value for the skin friction in both comparative cases. The actual state of affairs may be judged from the data in Figure 1, taken from a report of Dr. Prandtl (reference 1), which shows the friction coefficient for flat plates plotted against the Reynolds Number. The shaded portion denotes the Reynolds Numbers at which the model float experiments were made. (In general, the lengths of the models range around 1 m (3.28 ft.), part of which immerses, according to the speed. In planing attitude the wetted length amounts to several centimeters. The model speeds range between 3 and 10 m/s (9.84 and 32.8 ft./sec.) for the most important stage of the take-off, thus yielding Reynolds Numbers between 10^5 and 10^6.) The corresponding numbers for full-size floats and hulls range between 10^7 and 10^9, that is, at the very end of the plotted curve. The variation in friction coefficient in the range in which the models were tested becomes readily apparent. Curve I represents the coefficient of resistance for a purely turbulent flow and the small crosses, the corresponding test points for flat plates. Curve III shows the resistance coefficient for purely laminar flow and curve II for a turbulent flow with laminar entrance section. The larger the Reynolds Number, i.e., the longer the plate, the smaller the proportion of the laminar zone in the last type of flow which prevails in the foremost portion of the enveloped body. The resistance coefficient thus approaches that of the purely turbulent flow of curve I. The location of the resistance coefficient in the shaded portion with respect to curves I, II, or III depends primarily on whether the fluid, which strikes the object or the flat plate, was previously turbulent or whether roughness or corners or even vibrations in the test object have set up premature turbulence. One apparent defect of all model experiments heretofore is that they have been made precisely in that

zone about which the doubtfulness is greatest.

What the resistance coefficient for the skin friction actually amounted to in the different model towing experiments is difficult to ascertain; at any rate, it has never been determined thus far. And, assuming even that it was done, it still remains questionable whether much had been gained by it. To be sure, it then would be possible to convert the resistance, due to skin friction alone, somewhat better, regardless of the other resistance coefficients measured for the respective Reynolds Number. This method is accepted practice in shipbuilding. But by doing so we exceed the bounds of similarity in mechanics, because the difference of those coefficients precisely implies that the flow is no longer similar in all parts. Whether, and to what extent, the character of the whole flow, and through it, the remaining resistance, is affected by it remains an open question at the present stage of development. This applies, in a particular measure, to the float where it is not a problem of streamline body but of an object past whose edges the water flows and in whose critical zone, that is, at velocities where the resistance becomes maximum, the phenomena of separation precisely may have the most profound effect on the realization of the planing attitude and thereby on the resistance. This may have an entirely different effect because of the difference in Reynolds Numbers than conforms to the difference in frictional resistance alone. Being thus closely bound up with the phenomena in the boundary layer it hardly seems plausible, as far as concerns the total resistance, to eliminate, for the present at least, those difficulties through some kind of separation of individual resistances and conversion according to some particular law of similitude. The suggestion to simply subtract a certain percentage of the total resistance to correct for the friction is even less expedient, so long as 10%, and 20%, and sometimes even more than that are recommended to correct for friction.

Thus, if the potentiality of converting model experiments, which heretofore were made in an exceptionally unfavorable range of Reynolds Numbers, is doubted, the reasons elucidated above should prove convincing for they are irrefutable. One explanation, which seems very important to me, may be found by corresponding full-scale tests and comparative model tests, reference to which shall be made further on. The only proof hitherto was practical

experience gained from model tests. As far as I am able to judge, the Froude rule ensures quite acceptable results in most cases, notwithstanding the objections raised in the above discussion. The doubtfulness of the reduction, which in the final analysis lies in the nature of the model test and which can be eliminated only by giving up at the same time its principal advantage, that is, small sizes and low speeds, does not alone suffice to explain the above contradictory empiricism.

But aside from these reflections, there is still another reason which restricts the applicability of model experiments, at least of those published so far, and which does not lie in the nature of the thing; that is the lack of sufficient importance which needs be attached to the combined action of floats and wings. One unconditional stipulation for convertibility of one model test to larger scales is the well-known geometrical similitude not only with respect to the form of the float but also with regard to its position relative to the water surface, particularly of the trimming angle (equivalent to angle of attack for an airplane wing). As soon as the trim at take-off is no longer exactly the same as in the model test, the law of similitude can no longer be held responsible for any inaccuracies.

The dependence of the resistance on the trim is well known. But, since this angle, and the angle of attack, respectively, of the whole aircraft, is again dependent on the moment equilibrium, the float can assume the same angle only when a moment equilibrium of all forces (air, water, gravity, and shearing force) prevails at this angle in the starting aircraft, or at least be obtainable by control action, or else the float is in a different setting and reveals, as a rule, a different resistance than the one measured on the model. The first experiments were made in England. They covered a series of studies on the dependence of float resistance on the trimming angle and thereby on the moment about the lateral axis and were published by the British Advisory Committee for Aeronautics. Figure 2, taken from Reports and Memoranda No. 472, by G. S. Baker and E. M. Keary (reference 2), shows the results of those tests. The curves show the resistance and the moment about a lateral axis plotted against the trimming angle. The loading and the speed of the float were the same at all angles during the experiment. (The moment, in this case, was plotted against the C.G. of the seaplane for which the float was designed.)

This result shows the minimum resistance at around 5 to 6° for this float and speed. If there is no perceptible change in the corresponding moment, the change in angle is comparatively great, and with a change in trimming angle the resistance abandons its best position and rises, first slowly, then rapidly.

In Germany, H. Herrmann was first to publicly point out the practical significance of this effect. (Reference 3.) He proposed to the D.V.L. (Deutsche Versuchsanstalt für Luftfahrt) in 1925 to underwrite the expenses incidental to a test program patterned after the English studies. The D.V.L. responded favorably and commissioned Mr. Herrmann to make such experiments. They were made in 1926 in the experimental laboratory for shipbuilding at Hamburg and subsequently published. (Reference 4.)

Thus, even if a certain amount of experimental data was available from which some information could be obtained, it was far from being conclusive enough to furnish a clear, comprehensive explanation. All published data were always obtained in view of one particular seaplane, and the reports do not always include the stipulated presumptions, so that in such cases where the moment about the lateral axis changed and its effect was studied, it was impossible to tell from the reports what the actual amounts of these moments really were. (Unless the resultant moment is also given, the dimensions of the test set-up, respectively, the points of application and the magnitude of all forces should be stated, as is customary practice in the English reports.) Aside from this the available data are always given for limited sections by one certain loading or one certain trim, etc., so that not one of the published reports could be used to follow a get-away from beginning to end.

To obtain a clear insight into these questions, P. Schröder, the erstwhile expert of the D.V.L. on matters pertaining to floats, prearranged corresponding experiments and designed a test apparatus which, in contrast to that of the H.S.V. (Hamburgische Schiffbau-Versuchsanstalt) described in the report of Herrmann, Kempf, and Kloes, does not provide for reading the depth of immersion and the trim on a scale but by means of a continuous record during the entire test. This improvement turned out to be very advantageous because in the most significant attitudes the model usually executes combined vertical and

torsional oscillations about the lateral axis with more or less pronounced amplitudes.

These experiments were subsequently undertaken by the H.S.V. and carried out by the expert of the D.V.L. Another formulated test program was to embody the concerted efforts of the two institutes. The experiments were made in connection with towing tests for Rumpler's transoceanic project. The costs were mutually defrayed. The most pertinent data relating to those experiments and their interpretation have already been made public. (Reference 5.)

The fundamental importance of these tests on the subsequent considerations may be briefly summed up as follows: According to tests on three different float forms the resistance is most sensitive to changes in trim at the speeds where the boat goes on the step. Obviously, any slight change of trim then suffices to delay the planing attitude. At higher speeds the sensitivity becomes less, until upon approaching get-away speed, it becomes more pronounced again.

The effect of the location on the resistance and on the moment is easily explained. For the primary purpose of the stepped float is to raise the boat from the water by dynamic lift and to reduce the immersed area and thereby the frictional resistance. In the orthodox float arrangements the frictional resistance generally equals (computed with the coefficient measured on the flat plate) about 1/3 of the whole float resistance. Since, at the corresponding speeds only a slight excess in propeller thrust prevails over the total resistance, get-away would be hardly possible if the wetted surface were not at the same instant materially reduced by the dynamic water lift. Because the frictional resistance would increase practically as the square of the speed and the wing lift in this range of about 40% of the get-away speed would have no decisive effect as yet on the lift-off. At around 60% get-away speed the frictional resistance alone would already exceed the total resistance of the conventional floats.

When the boat has exactly risen to step the water beneath the step still passes very closely along the afterbody. If the trimming angle is too high the afterbody or part of it becomes easily immersed and increases the resistance. On the other hand, if the trim is too small, the float will not produce the necessary amount of dynamic

lift; it lies, on the whole, still deeper in the water, which again increases the amount of wetted area and consequently, the resistance. The reason the going-on the step is so sharply defined and accompanied by the typical hump speed (resistance maximum) is due to a suddenly produced attitude where the afterbody lifts off from the water.

As the speed increases the float continues to climb out of the water; first, because the wing lift increases, and second, the water mass, to which a downward acceleration must be imparted in order to be able to produce the necessary lift, diminishes as the speed increases. Now the forward supporting part of the float acts similar to an airplane wing (because of the small wetted area, the frictional resistance plays a subordinate role), in which the resistance also is primarily dependent on the amount of lift and to a lesser extent on the circumstance of whether this lift is produced by a thick wing at low angle of attack or by a thin wing at high angle of attack. But the afterbody is so far above the water that the trimming angle is amenable to changes within a certain extent without immersing again. When the trimming angles become too small, the wetted supporting area ahead of the step naturally becomes greater in this attitude and the result is a much greater resistance after a certain change in angle.

Many floats show a pronounced sensitiveness just prior to lift-off. The explanation for this is the necessity of ensuring large trimming angles in this range in order to start with maximum wing lift, i.e., lowest possible speed. As a result thereof the wave, which is formed aft of the step, again clings close to the afterbody and a slightly greater trimming angle (afterbody placed too low in the design) suffices to cause immersion. Figures 3 to 5 show the results for one of the examined floats at two different loadings. The moment is with respect to a lateral axis through the step. At 10 m/s (32.8 ft./sec.) speed, which about brings it in the neighborhood of the hump speed, particularly when the float is highly loaded, the retention of the correct trim is of greatest importance, while at other speeds this effect is not quite so significant.

A simple reflection reveals qualitatively the behavior of the moment about the lateral axis during the take-off process, (confined to the moment which the forces of

the water exert upon the float).

In the rest position the resultant of all water forces attacks in the center of the displacement, and this is generally near the step. As the boat is started, the bottom in front of the step commences to produce dynamic lift. Thus the resultant water force shifts forward and the float trims more and more by the stern up to the moment where the boat is on the step and all lift is produced ahead of the step. As the speed increases the boat then continues to rise out of the water and the supporting area is thus reduced. The consequence is a backward displacement of the resultant and finally a coincidence with the edge of the step at the moment of lift-off. In this second phase of take-off the tail-heavy moment becomes smaller again until the forces of the water, and thereby the moment, disappear. A recurrent immersion of afterbody or any other part of the float while planing, naturally disturbs this kind of moment behavior. According to the distance of the respective parts away from the step, they are capable of setting up considerable moments.

Unless these moments during the take-off process are taken into account in the design and the C.G. of the airplane is located far enough forward, the afterbody still remains in the water, even if the dynamic lift at this speed were high enough to raise the boat to step. The aftermath would be high frictional resistance and a bad, if not altogether impossible, take-off. This, I think, is the physical explanation of a phenomenon which seaplane pilots often express by "the afterbody sinks fast."

The conclusions to be drawn from these considerations are the following premises governing the installation of floats, and whose observance or nonobservance is a dominant factor on the take-off characteristics. To ensure satisfactory cooperation between float and seaplane, the location of the C.G. in front of the step must be so chosen (by very high propellers the best C.G. may even be located aft of the step) that a moment equilibrium prevails by neutral control setting at that trim at which the resistance is approximately minimum. This, of course, includes all moments about the lateral axis set up by the forces of air, water, propeller, and its own weight. At least it should be possible to obtain this range of trimming angles by control action. Furthermore, the angle between longitudinal axis of float (more exact, of the float line with respect to the trimming angle) and the wing chord must be

so chosen that the wing produces the necessary lift for starting at angles to which the minimum float resistance belongs.

As obvious as these two rules are, they nevertheless were not taken into account in sufficient measure in the published model tests. In the first place, many published model experiments were made at one trim only. In most cases this is a different setting at each speed, because the moment varies about the lateral axis according to the above explanation. The sequel is that the model, which is usually mounted so as to permit rotation about the lateral axis, assumes a position which is dependent on the more or less accidental kinematic conditions of the mounting method. Because of the measurement at only one trim, the model float forms examined in this manner are not quite comparable, aside from the aspect of conversion to other scales. For it is impossible to judge from one of two tested model floats, towed perhaps at a more unfavorable trim and which for that reason seemed worse, whether or not it is in reality superior to the other which by chance happened to be measured at the trim for which its resistance is lowest.

Having selected a float form which showed suitable qualities as model gives us the resistance coefficients for a certain trim at any speed. Now if it is desired to arrange this float conformably to the above postulates and to maintain during the take-off process the angle of the model test at any speed, it implies that a certain angle of attack of the wing is specified which changes more or less accidentally during the take-off in the model float. If the model test stipulated only one loading, decreasing with the square of the speed, so that at each speed the resistance was defined for one loading only, the actual seaplane generally will no longer have the same lift as presumed in the model test. Still, many model tests are conducted in this manner. In spite of variable trimming angle a constant angle of attack is presumed. At low speeds it usually is not so bad, because at starting the angle of attack is not the same as assumed by the model measurement. But at high speeds (hump speed to get-away) this effect may become of vital importance.

The result of this limitation to one loading is that the data cannot be reliably applied save for aircraft with a well-defined starting speed. The starting speed for which the model measurement was determined, is at the same

time fixed by the scale of enlargement. But as a rule, the seaplane, for which a float measurement is needed, has not the same starting speed as assumed by the model with a view to any definite design. As a result, the doubtfulness, when applying such results, becomes still greater.

Besides, the correct criterion for a satisfactory start is not merely a minimum float resistance, but rather a minimum total resistance of wings plus float. This minimum of the whole system does not, or at least not at all speeds, coincide with the minimum for the two individual components. To ensure an absolute minimum, the attitude of the float to wing would have to be capable of changing during the take-off process. Hence a compromising solution is inevitable, and the endeavor will be to take special notice of the attitudes which seem most critical in the present construction problem.

But in order to effect such a compromise, the resistance of the float in the different questionable positions would have to be known, aside from the moment of the float at the different speeds, trims and loads within the scope in question, to ascertain whether the specified position is at all obtainable, and to effect the disposition of C.G. to step and the setting of wing and float in such a manner that the seaplane makes a good start without help if possible (as many do). The fact that these viewpoints are not sufficiently recognized in model tests is much more responsible for the distrust in the application of model test data than the errors incidental to reduction by Froude's law of similitude. The consequence is that the published float measurements cannot be used in the true spirit of the model test and in the light of accepted practice of publishing airfoil data, namely, to select one tested shape and then be able to find all necessary numerical data therefrom.

The behavior of the different moments set up on the seaplane may be seen from Figure 6, which was taken from the data of an experimental seaplane, and which is to be used for float tests. The figure shows the moments of float resistance and float lift, both assumedly applying at the edge of the step, the wing moment including propeller by zero control setting, all with respect to the C.G. of the seaplane. It shows, in addition, the moments obtainable by certain elevator displacements β, once when

the slipstream strikes the control surfaces and once when it does not. The basic speed about corresponds to the hump speed. The moments which can be set up with the control surfaces are, as seen, comparatively large with respect to the other moments, when the tail surfaces are in the slipstream. It is largely by virtue of this fact that the application of model test data is ordinarily successful; for through it, it enables the pilot to make up for many things which could not be taken into account during the construction. However, even then the setting between wing chord and float must be such that the correct angles of attack, particularly the maximum wing lift, can be obtained in the last stage of take-off without wetting an unnecessarily large float area. But if the tail surfaces are blanketed from the slipstream, the obtainable moments are very small and in such aircraft the exact compliance with the two conditions, discussed above, is essential to assure a passable starting performance.

This matter assumes special significance when the float has two steps. So long as the two steps are actually supporting, the moments necessary to change the trim are so large that they cannot be produced by the tail surfaces. Incidentally, it is very important in this case to be able to investigate carefully the setting of wing and float, and to confirm the presence of the correct angle of attack of the wing, particularly immediately preceding get-away. Since boats with two steps quite often run on one step only in the last stages of take-off, while on the other hand, the part of the boat between front and rear step is very close above the water, the danger that this part may immerse again by slight changes in angle of attack, is very great. Here the coaction of wing and boat requires particular attention.

Model test data, especially when intended for publication, i.e., destined for general information, should not be ascribed to one particular seaplane, and should embody the qualities of the float as detailed as in the case of wing sections, namely, as regards lift, drag, and moment about a lateral axis which, although arbitrarily selective, should nevertheless be incorporated in the test report. After we had completed our investigation we heard that Mr. Tank of the Rohrbach Company, had made a great number of towing tests in the above-described manner and that his experiences relative to reduction to full scales were very satisfactory. But such test data as these,

which would be of inestimable value, are invariably never published.

The question whether, and how, it is possible to make model float tests which are applicable to any seaplane regardless of size, and what data a complete model measurement should embody is now in order.

Since every seaplane design is for a specific gross weight, the scale of enlargement of the tested float is decided to within certain limits. According to the intended purpose of the seaplane, a proven float form may be loaded perhaps 10 to 20 per cent higher or lower. (If necessary, the stability can be modified by appropriate design of the superstructure.) Under these circumstances it would be desirable to know how the qualities of a float would be modified under say, a 15 per cent higher, and a 15 per cent lower than normal loading. For that reason a series of float tests with three different initial loadings: normal, somewhat below, and above normal should be begun now.

The get-away speed in the design of all seaplanes is contingent upon the choice of wing section and with it, on the manner in which the wing lift changes with respect to the speed during take-off and thus reduces the load on the float. Now the starting speed of seaplanes of identical size fluctuates perhaps 15% above and below a certain average, and if the float loading for the three selected initial loadings were now made in such a way as to decrease in the usual manner with the square of the speed, while on the other hand, the three get-away speeds for the three different weights likewise varied by 15 per cent, as indicated in Figure 7, it would reveal the float loading for all practical seaplanes of this size. Moreover, it would not only show the loading at a certain stage of reduced wing loading but at any other arbitrary one as well which might occur during take-off; for the interpolation between these three curves would also reveal any other reduced load curve. In this manner the applicability of the test data for seaplanes of the same size would be practicable regardless of the get-away speeds which vary within certain limits according to the purpose for which they are intended. In addition, it would make it feasible to follow the start of an overloaded seaplane, which is an important factor by the increasing need for long range seaplanes.*

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*In a model test, made by G. S. Baker and E. M. Keary, the load reduction was similarly chosen. (Reference 6.)

Now what is the result when it is attempted to apply such model test data to seaplanes of sizes different than that for which the model test was made? According to Froude's law of similitude corresponding speeds are available for a seaplane of different size when the speeds vary as the sixth root of the gross weight, or in other words, as the square root of the dimensions. (In twin-float seaplanes the proportion of the gross weight entrained by the float is, of course, decisive.) Hence, every test point may be transferred to seaplanes of any arbitrary size provided the get-away speed of that seaplane is proportional to the sixth root of its gross weight. This stipulation corresponds to Lanchester's derived law for the enlargement of aircraft, and the practical development has, in fact, followed along those lines. Figure 8 shows how the starting speed must increase with the gross weight to ensure conversion to arbitrary sizes. The three curves represent the starting speeds plotted against the gross weight for the above three loadings as obtained by reduction of the discussed model test with three different float loadings according to Froude's law. It includes all seaplanes of which I could obtain any data. It is seen that by far the greater percentage of starting speeds lies between the values predicated by the model test, so that the test data are applicable to all these seaplanes at any arbitrary attitude by interpolation. Those seaplanes in which the starting speed is considerably higher, are racing planes with very high speed, and for whose float other factors are, moreover, involved, since here it becomes a matter of minimum drag rather than seaworthiness.

A float test made in the above-described manner can be applied to normal purpose aircraft ranging from the smallest twin-float seaplane to the largest flying boat.

This advantage should be utilized. I believe that the test data of about ten typical floats would supply all the necessary information for any normal design problem, and a large portion of the float resistance question, as far as concerns the practical application, would be eliminated. Of course, there still will be possible variations. But if this test is already made selective to a certain extent, that is, confined to accepted forms or to such which according to preliminary tests are acceptable, it should be possible to find a suitable form for any purported use.

To be sure, the resistance and the moment at various trims would have to be measured for each lift and for each corresponding speed, to enable the designer to install the float correctly as well as to make it possible for him to follow the equilibrium of the moments and of the forces at any position and speed which might occur during the take-off. The many variables naturally make a great number of test points necessary for a complete float investigation.

Thus a complete test at say, ten different speeds under three different loadings, and at from 4 to 5 different angles of attack, requires altogether about 130 test points or stations.

On the other hand, it should be borne in mind that this is the primary purpose of the model test; first, because it makes the model tests comparable to one another, second, it permits installation so that the best possible take-off qualities are actually obtainable and lastly, it ensures the application for all subsequently designed seaplanes regardless of size. This undoubtedly makes this method more simplified and less expensive than when the measurements have to be repeated for each seaplane, and which, even if intended to serve but that special purpose, is nevertheless not much smaller in scope.

Aside from the float resistance, the strength at start and landing is of greatest significance for the seaworthiness. A normal landing in smooth water presents no difficulties. But by landings in seaway the pronounced shock-like loads are difficult to control from the construction standpoint. The points of view on how the impact phenomena are enacted and what quantities are primary factors, are still at variance.

A qualitative, comparatively easy insight into the physical principles of the problem involved may be obtained by applying the laws of impact in electrical mechanics to this process. But this is not to imply that its theoretical solution is simple.

The conditions for the impact on the flying boat being too complicated, we begin with the most elementary case, namely, an object dropping on the water. The bottom of the object is assumedly flat, and drops from an arbitrary height on a smooth water surface, the flat bottom striking the water in its full extent. Now two things may

happen. The object of any arbitrary but finite weight is decelerated to zero velocity the instant it strikes the water or else it penetrates it at finite speed. If water and object were not elastic the force of impact (hence, the pressure) would have to become infinitely large in both cases, for in the one case the object with finite mass is slowed down from a finite velocity to zero within the infinitely short time interval. In the other case, a finite water mass is set in motion at the moment of contact and accelerated to the velocity at which the object penetrates the surface of the water. Thus, we have in both cases infinitely large accelerations and decelerations and, according to the fundamental law of mechanics, infinitely great forces.

The real force (pressure) is, of course, not infinite, or the object at least, would be destroyed. The fact that the force of impact remains finite, is solely due to elasticity. In a rigid object the elasticity of the water would also be of significance. But in flying boats with their flexible bottom planking and their other elastic members, the elasticity is so high compared to that of the water that the amount of the pressure is essentially determined by the elasticity of the float rather than by that of the water, so that the latter may be considered as being incompressible.

The effect of the elasticity of the object is manifested in the following manner. At the instant the object touches the surface of the water only the lowermost infinitely thin film is retarded; the other parts still retain their motion. As a result the object is compressed, and an elastic body is not able to transmit a force from one particle to another until a form change occurs. The elastic forces set up by the deformation then impart to the lowest layer, and thereby to the water, a downward acceleration and retard the other parts. At the initial moment the incipient force is small because the deformations are small. But as long as the upper parts of the body still move faster than the water, the body is more and more compressed and the force, and through it the acceleration, impressed on the water increases. This increase continues till the maximum of compression is reached. Then the form change recedes, and as the object regains its former shape, the force of impact becomes zero. As a rule, an object deforms toward one side or the other once it has been compressed and then extended beyond its zero position. Be-

ginning at that moment the force of impact would act as tension and this would continue back and forth several times until this oscillation had been damped out. Our interest is centered in the first stage of the process up to where the maximum force of impact is reached.

Applied to the case of the float, this means that the bottom planking may be considered as the lowermost, infinitely thin film of water which remains during the first instance of contact. The other masses of the float and of the aircraft still continue to move at the same rate of speed. As a result thereof, all elastic members are compressed, and a force begins to act on the bottom and through it on the water mass. The more supple the elastic connection, the slower the rise of this force impressed on the water. The acceleration of the water is divided over a longer period and the impact is lessened.

This postulate on the impact holds true regardless of the form of the float. Whenever a finite piece of the float planking strikes a portion of the water surface which is exactly parallel to the planking, nothing can prevent breakage save the elasticity.

Aside from the effect of the temporal course of the impact process, stipulated by the elasticity, on the force of impact, the extent of the area which simultaneously contacts with the water is also of vital importance, for it defines the amount of water mass to be set in motion. This is dependent on the form of the float and on the form of the water surface. When a keeled float settles on smooth water, a very small water mass is accelerated at the moment the keel immerses. As the depth of immersion increases the immersed portion expands, and with it the water mass, until at last the entire bottom is in the water. The keel effect here acts similar to the elasticity, namely, the keel divides the momentum over a longer period. The only difference is that the keel does not set the whole water mass into motion at once, but first brings a very small water mass directly to finite speed which then continues to expand. In contrast to this the elasticity manifests itself so that the entrained water mass may have a finite magnitude from the very beginning, but instead of being instantaneous, it is gradually accelerated to a finite speed.

These deliberations were mathematically developed

along with suitable experiments for idealized conditioms by W. Pabst (reference 6), and have already been published.

From the considerations on the effect of float form, the conclusion may be drawn that the stipulation of low resistance and small force of impact is contradictory as far as concerns the form itself. A small resistance for a given lift is obtained when the largest possible water mass combined with minimum immersed area is imparted a downward acceleration. A small force of impact is contingent upon the accelerated water mass showing an exceedingly slow rise as the depth of immersion increases, and by virtue of the thus necessitated form, the area as well as the acceleration imparted at the sides of the water, become larger. At starting, this results in resistance which does not contribute to the lift. On the other hand, the medium keeled bottom reduces the impact force very materially without, however, any pronouncedly higher resistance, so that a medium keel is always acceptable.

Heretofore, a smooth water level had been assumed, while in practice, the process in seaway is of primary interest.

Whereas the conditions are exactly as in smooth water in a qualitative sense, it never will be possible to define quantitatively the impact forces based upon a theory. The seaway is extremely multiform and comprises waves of any length, and which do not, as a rule, run in the same direction. Hence it is not possible to effect a calculation for all forms of water surfaces which may happen at the moment of contact. Moreover, this is necessary because it still is possible to predict beforehand in principle, what the result will be, as already stated above. If the form of the water surface, at the place where the float sets down, is exactly such that a greater portion of the surface is parallel to the planking of the float, so that in the very first instant a greater part of the float strikes the water, the float will be damaged, no matter what its form, unless elasticity intercedes.

But even the appearance shows that the advance stipulation, namely, the corresponding form of the water surface at certain places is always given for heavy sea as well as for relatively small waves, excepting that these conditions are only more or less frequently available according to the structure of seaway and shape of float.

They are most frequent when the wind has turned shortly before starting or landing, so that waves from every direction overlap one another. The most dangerous waves for keeled and flat float alike, are those rolling in from the side. In fact, this accounts for the many cases where a seaplane is damaged in moderate sea after having successfully undergone its seaworthiness tests in much heavier sea.

It is readily apparent that the problem here is essentially a static one and that the primary object must be to define by what forms - in dependence on the respective seaway - the advance stipulations are most frequently given for great impact forces along with the extent of this frequency. Experience has shown that keeled forms are better in seaway than others, for when the waves roll up from the front - which is at least approximately quite frequently the case - there is no fundamental difference from the process in smooth water. Only the speed of impact is higher because of an additional component of the path velocity due to the inclination of the water surface, aside from the pure sinking speed. Thus the keel has a shock-reducing effect. Still no form can be found which is not occasionally subject to the same high impact forces as those which are less favorable, when the conditions prevail as outlined above. The frequency of high impact forces may be reduced by correct float form, and it should be done, of course, as far as possible, even though this does not altogether preclude their occurrence. The only remedy for lowering the impact forces, even by the worst position, lies in the choice of appropriate elasticity.

I do not hold the fear of elastic floats and float bottoms to be wholly justified. Taking into account the extremely short periods during which the impact occurs, even a small amount of elasticity suffices to considerably lower the impact forces. The elasticity as it prevails to-day in most cases even without aid on part of the designer, and being conditioned only upon the structural material, is ample enough to reduce the pressure from infinity to about 3 atmospheres. (This is the highest pressure recorded by the D.V.L. for a flat bottom float.) It is outside the ambit of this report to enter into a discussion on how to select the elasticity so as to ensure sufficient flexibility against great impacts in order to reduce the forces, and at the same time avoid all disagreeable deformations incidental to load variations. These load changes are due to the varying float immersion depths, the

float alternatingly riding the crest and then the trough of the waves while the float itself firmly maintains contact with the water. These fluctuations are generally much slower than the impacts exerted upon it when the float was wholly out of the water and then immersed again. Thus, it seems plausible to so choose the elasticity that the float itself may be considered as practically rigid with respect to the slow lift changes and still be flexible enough to lower the short-lived impacts. In this way the seaworthiness may perhaps be improved, whereas the forms which heretofore have proved their practical worth are hardly amenable to much more refinement.

As a result of these deliberations, our next step was to measure the impact forces for as many landings in seaway as possible. If independent thereof, the elasticity is simply determined by experiment; the principles as outlined above, furnish a comparative basis for the results. Based upon the known elastic properties and the measured impact force, the extent of the area and the entrained water mass which has to be available, is calculated. This, while yielding but an average value, still helps to clarify matters considerably.

The principal difficulty encountered in these experiments, was the lack of suitable test methods to fit the requirements. After manifold attempts, the problem has now been solved successfully. Since the test method has already been described at various times, as, for example, in the paper of Pabst (reference 7), we briefly mention that the method consists in measuring full scale the elongation of the structural members, such as struts of the flotation gear, float members, etc., by means of an elongation recorder. The record is obtained from a diamond scratching upon a moving glass plate, which is subsequently interpreted under the microscope. With a sufficient number of test stations the deformations, and thereby the force, can be determined along with the resultant forces of impact. The maximum local pressures are recorded on indicators in conjunction with the elongation recorder. Because of the results of these experiments, the above-mentioned report merits special notice. Figures 9 and 10 were taken from the same paper. Figure 9 shows the resultant force of impact at alighting and its location with respect to the seaplane, while in Figure 10, the numerical values of the individual impact forces (in t) and in load factors are plotted against the time.

In order to obtain results of a more general nature, the study of any representative type of floats should be supplemented by tests on floats with systematically varying forms as well as systematically changing degree of elasticity. It would not require so very many. Six to eight different kinds of floats would help a great deal.

A secondary problem of the impact forces is the measurement of the seaway. The first step should be to define the character of the seaway near the landing place to ensure a basis of comparison. Preliminary studies in this direction are under way. But for the actual impact process it would be very desirable to ascertain the form of the water surface at the point where the float settles, but for which I can see no way at present which would be practical to use in seaway. So the problem must be solved by channel tests.

As far as concerns the resistance, I have already pointed out the method by which the tests should be made so that the data may be applicable to any seaplane of arbitrary size. We intend to make such tests on the seaplane itself as well. In that way it eliminates any difficulty through the effect pointed out above in connection with the model measurements. The test set-up, begun four years ago, but postponed from time to time on account of shortage of personnel, has at last been completed. It consists of a flotation gear and a seaplane of about 2000 kg (4410 lb.) gross weight executed as three component balances on which one lift component each, front and aft, and the resistance is measured. The inclination is photographically recorded, and the speed by a specially designed Pitot tube. These experiments simulate taxying on smooth water at constant speed, at which the stated quantities are measured. If necessary, the effect of water depth will be included. The first trial measurements have been made and I hope to be able to start the actual experiments in the very near future.

While outlining the future aims of these studies, I do not wish to imply that everything will be carried out in the near future by our own sole efforts but rather that it presents a better picture of the whole by stating the ultimate aims of all these purported preparations. Our program calls for resistance studies on (perhaps 6 to 8) different floats in conjunction with comparative tests on corresponding model tests in the seaplane towing channel.

This is to be followed by measurements of the impact forces and their distribution over these same floats in seaway and the interpretation of any eventual changes in resistance and the total starting characteristics with respect to smooth water. Lastly, the stability of the floats is to be determined. Then, if the whole test data are comprehensively compiled in the representative manner of wing section data, it will provide a foundation which, even though continuously in need of modification, still would make for a certain clearness of the problem and thereby become a great help in the future development of the seaplane.

The report was followed by an animated discussion which, however, cannot here be repeated verbatim, for lack of space. I therefore attempted by means of stenographic notes, to pick out the main points as the debate went on. My own remarks are given in brackets.

Dr. Schröder pointed to the possibility of limiting the number of tests by means of a reduction law (see Zeitschrift für Flugtechnik und Motorluftschiffahrt, 1931, page 9), which makes it possible to compute the corresponding quantities for different planing attitudes with different load and speed from the resistance and moment, respectively, measured in one planing attitude.

[Such a law would be very useful, indeed, and we shall avail ourselves of such possibilities as far as is feasible to do so.]

Mr. Bock spoke of the inherent difficulties in all airplane measurements when attempting to establish suitable test methods. He was gratified to hear that the D.V.L. methods, which were used by the Junkers company for different experiments, had proved successful here also.

Dr. Töpfer commented that in applying such data, as obtained from float experiments, to future specifications, special purpose aircraft, such as fast mail airplanes must, in particular, be taken into consideration, if that phase of development is not to be retarded. Because of their high landing speed, which such aircraft must have, the conventional requirements here are very difficult to comply with.

Professor Dr. Hoff observed that the specifications should be considered as something that could and would

have to be modified as progress warranted.

[In the paper no thought was given to structural specifications, but rather to the explanation of the problems involved.]

Dr. Seehase referred to the keeling effect and cited the specific case of a keeled float bottom with downward protruding longitudinal strips below the board walls, which upon being removed, resulted in materially reduced force of impact. He also inquired about the accuracy of the elongation recorder and the errors of the optical enlargement.

[The longitudinal strips on a float effect an increase in the accelerated water mass. At the moment the strip dips into the water there still exists a certain amount of air space between strip and float bottom. As soon as this whole space is filled with water a certain mass of water must suddenly be set in motion, whereby the strips prevent the flow past the edges similar in effect to the end plates on an airplane wing.]

[The errors of the test instruments range around .003 mm (.00012 in.) when handled correctly, and they are caused by the inaccuracy in the carrier guide, elongation in diamond holder, etc. The optical enlargement is, in any case, the most accurate in existence anywhere.]

Translation by J. Vanier,
National Advisory Committee
for Aeronautics.

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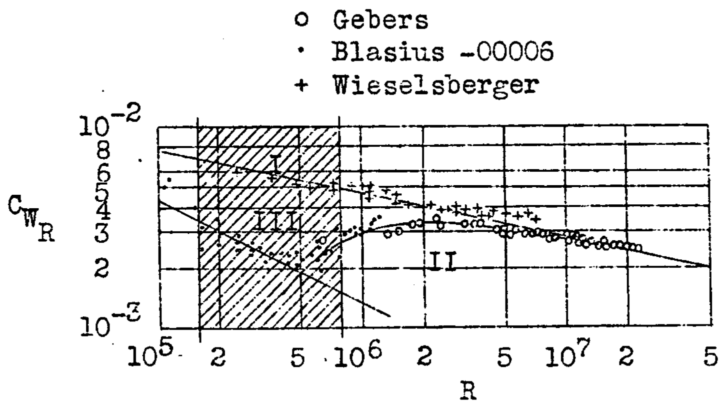
o Gebers
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10^{-2}
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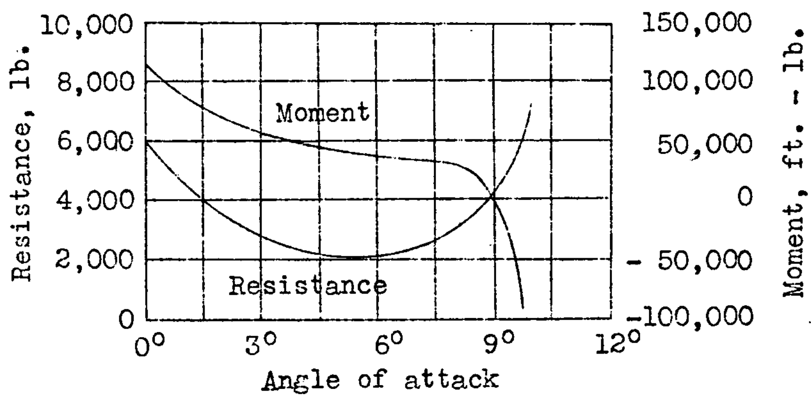
Fig.1


10,000
8,000
6,000
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Resistance, lb.
150,000
100,000
50,000
0
- 50,000
-100,000
Moment, ft. - lb.
Moment
Resistance
0°
3°
6°
9°
12°
Angle of attack

Fig.2

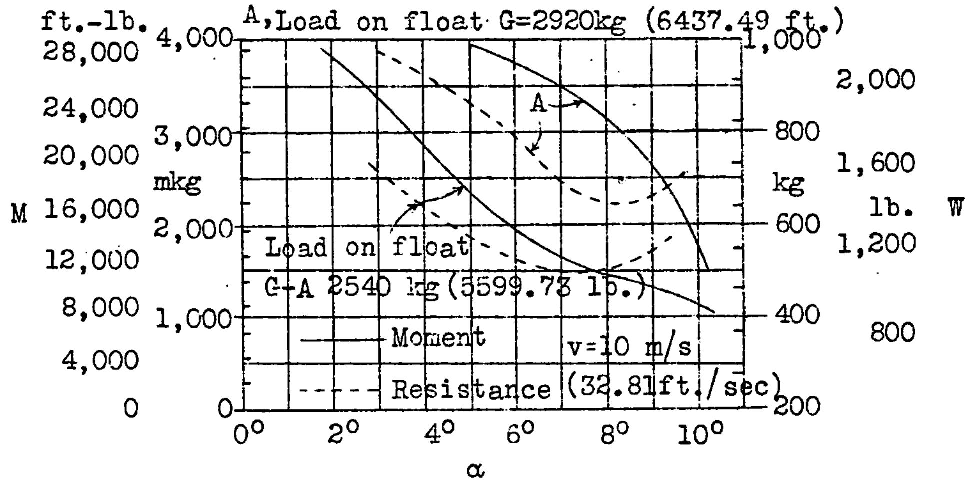

Fig.3 Moment and resistance for constant loading and constant speed plotted against angle of trim. (0.4 starting speed).

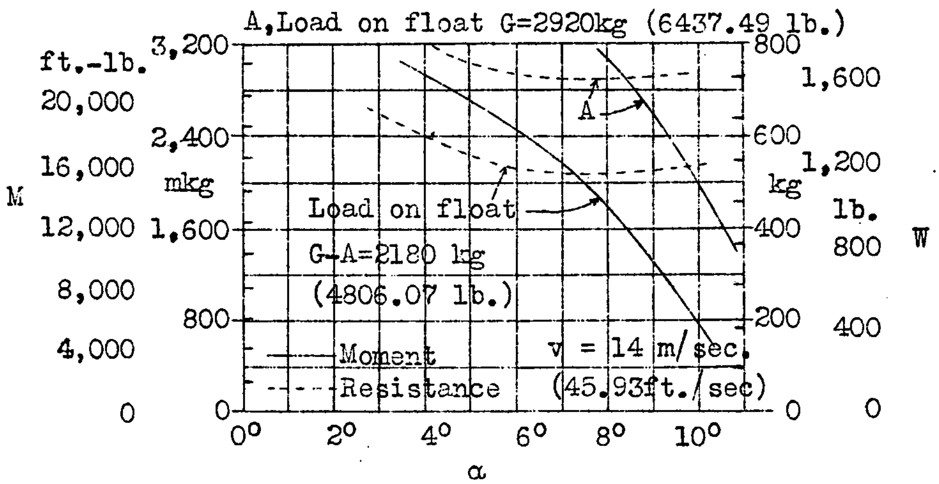

Fig.4 Moment and resistance for constant loading and constant speed plotted against angle of trim. (0.6 starting speed).

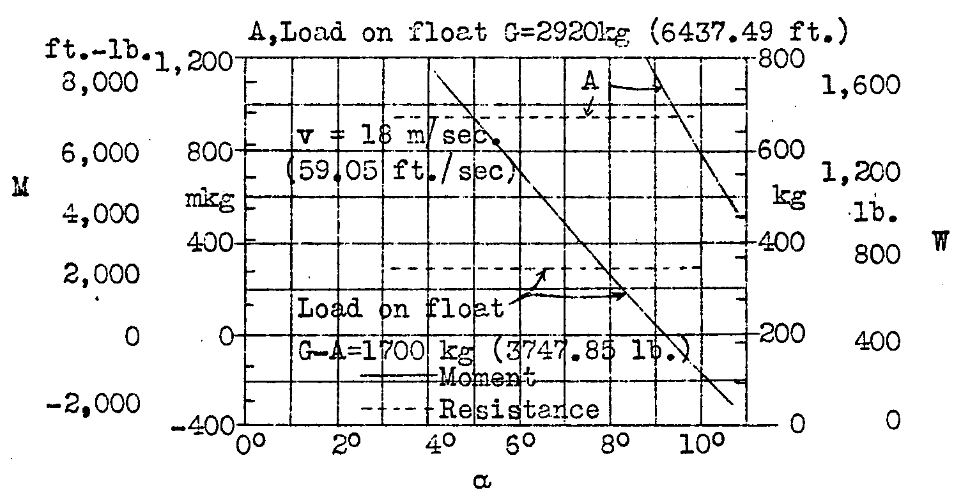

Fig.5 Moment and resistance for constant loading and constant speed plotted against angle of trim. (0.75 starting speed).

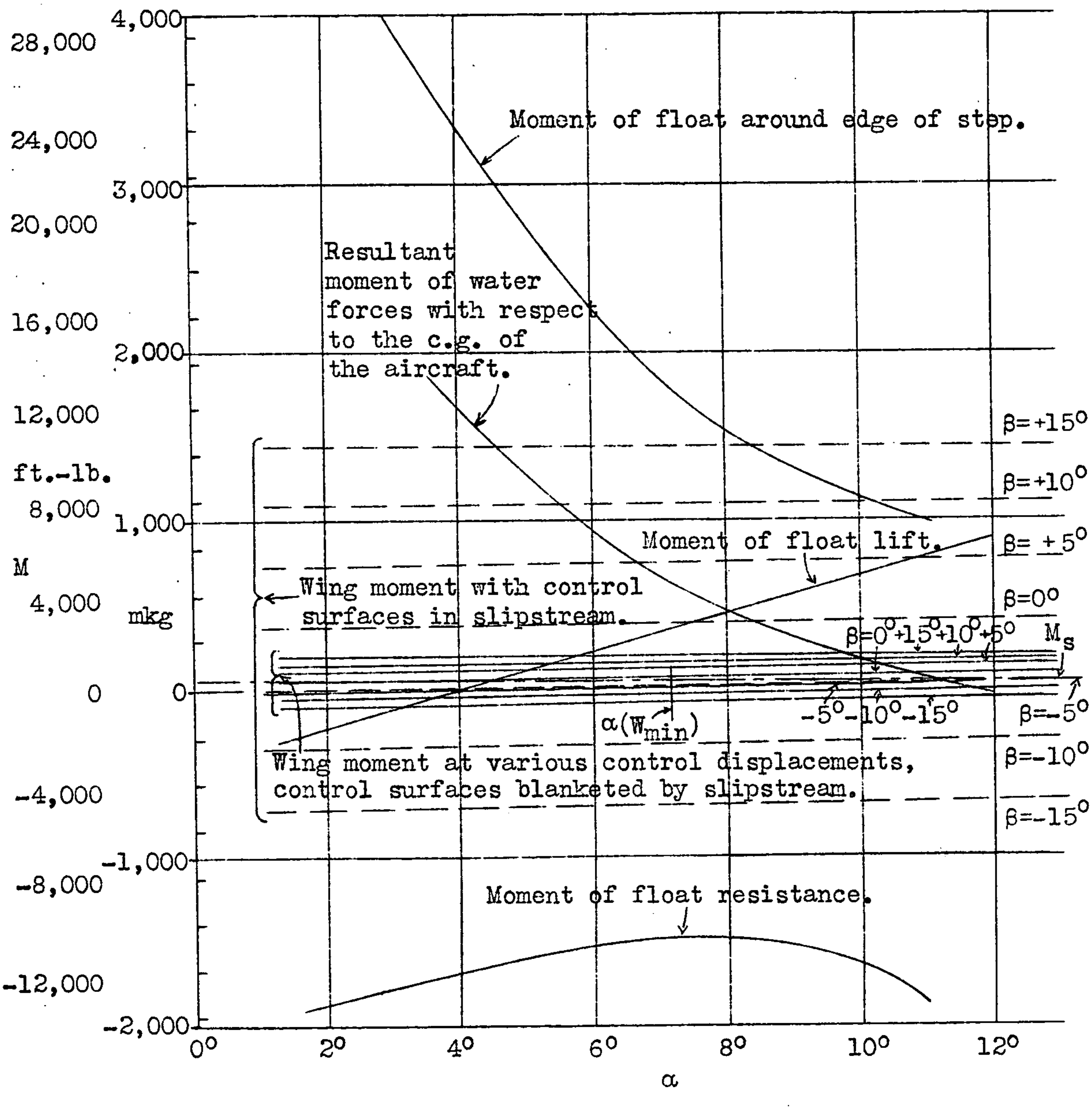

Fig.6 Wing moments (inclusive of propeller and control surfaces) at various control settings β and water forces with respect to the c.g. of the aircraft.

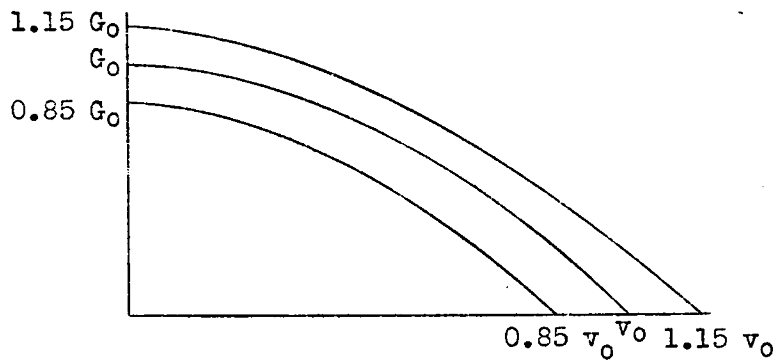

Fig.7 Reduction of load in model float tests.
G_0 = normal gross weight (proportion of float).
v_0 = mean starting speed of aircraft of this size.

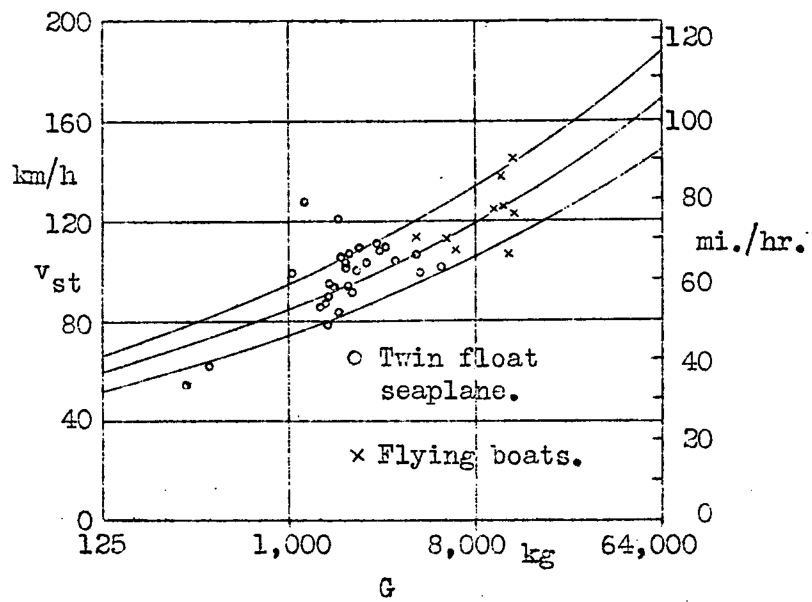

Fig.8 Starting speed of present day seaplanes plotted against gross weight. The curves represent the starting speed after reduction conformably to Froude's law from a model test with unloading according to Fig.15.

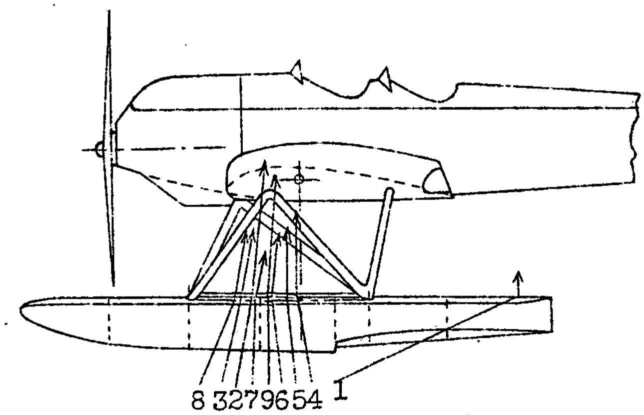
8 3 2 7 9 6 5 4 1

Fig.9

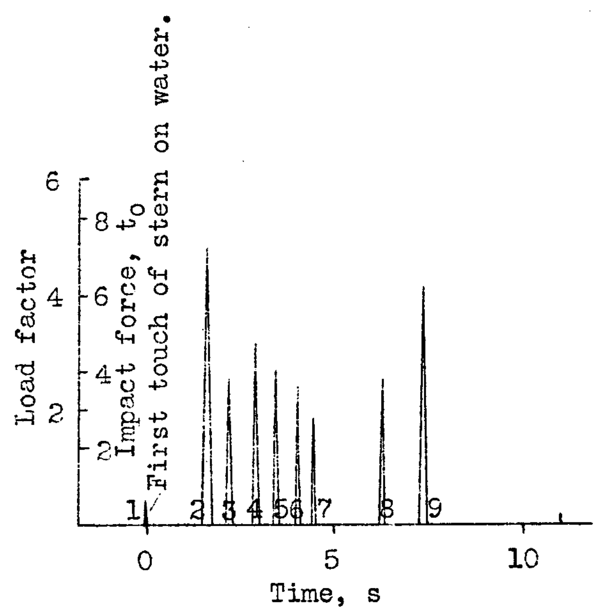
Load factor
Impact force, t_o
First touch of stern on water.
0
5
10
Time, s
1
2
3
4
5
6
7
8
9

Fig.10